AAS 94-138

TOPEX/POSEIDON ORBIT DETERMINATION USING GLOBAL POSITIONING SATELLITES IN ANTI-SPOOFING MODE

Joseph R. Guinn*, J. Rodney Jee† and Timothy N. Munson†

Results of orbit determination for the TOPEX/Poseidon (T/P) mission using the Global Positioning System (GPS) during Anti-Spoofing (A-S) activities are presented in this paper. During A-S tracking the T/P GPS flight receiver is unable to collect dual frequency measurements from the GPS constellation and thus unable to calibrate the observations for ionospheric delay. An approximation of the ionosphere above T/P can be obtained by differencing the available single frequency carrier phase and pseudorange measurements. With this technique, sub-decimeter radial orbit comparisons are obtained with solutions determined from SLR and DORIS tracking.

INTRODUCTION

The TOPEX/Poseidon (T/P) satellite carries a high precision Global Positioning System (GPS) receiver. During it's first year of operation, all of the available flight receiver measurements were processed. Outages during this experimental phase were primarily related to Anti-Spoofing (A-S) operation of the GPS constellation. Updates to the flight receiver software and ground processing procedures were implemented to produce near continuous operation during A-S.

Elements of T/P GPS orbit determination include the GPS satellite constellation, GPS flight receiver on-board T/P, six globally distributed GPS ground receivers, the GPS Data Handling Facility (GDHF) and the GPS Data Processing Facility (GDPF). The GDPF collects the GPS flight measurements from the T/P flight operations team while the

* Member of Technical Staff, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109-8099. Member AIAA.

† Member of Technical Staff, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109-8099.

ground station data are obtained through the GDHF. Carrier phase and P-code pseudorange measurements from 24 GPS satellites to the seven GPS receivers are then processed simultaneously with the GDPF software MIRAGE to produce orbit solutions of T/P and the GPS satellites.

With no A-S, orbit solutions based solely on the GPSDR observations and a global network of six ground receivers compare at the three to four centimeter (radial, RMS) level with orbit solutions derived independent of the GPS data [1-3]. During A-S, the orbit solutions show comparisons of five to six centimeters (radial, RMS).

OBSERVATIONS DURING ANTI-SPOOFING

During A-S tracking the T/P GPS flight receiver tracks only the L_1 carrier and CA-code pseudorange [4]. Thus, the ionosphere calibration based on the linear combination of the L_1 and L_2 carrier signals is unavailable [5]. For the GPSDR, a rough ionosphere calibration is computed by differencing and smoothing the single frequency carrier phase and pseudorange. The GPS receivers used at the ground sites have an advanced hardware design that allows for the reproduction of the full wavelength L_2 carrier phase [6-7], thus; the ionospheric calibration procedures for ground stations are unchanged.

Flight Receiver - An approximation of the ionosphere above T/P can be obtained by differencing the available carrier phase and pseudorange measurements. This difference is smoothed to remove the multipath associated with the pseudorange measurements. The remaining signal consists primarily of ionosphere. The following mathematical description shows the procedure:

1) Form $\Delta = L_1\text{-}P_1 = \rho + I + B_L - (\rho - I + M + B_P) = 2I - M + B_L - B_P$

where: L_1 = CA-code carrier phase
P_1 = CA-code pseudorange
ρ = True Range
I = Ionosphere
M = Multipath
B_L = CA-code carrier phase bias
B_P = CA-code pseudorange bias

2) Smooth Δ with cubic splines to remove multipath; $S(\Delta) \approx 2I + B_L - B_P$

3) Apply remaining ionosphere calibration to L_1 and P_1

$L_{1C} = L_1 - S(\Delta)/2$
$P_{1C} = (L_1 + P_1)/2$ and carrier added smoothing

Figures 1-4 give examples from the observation processing. T/P flight receiver pseudorange measurements, from one of the GPS satellites (PRN 31), are shown for 10 passes in Figure 1. Performing the standard linear combination of dual-frequency carrier phase measurements yields the true ionospheric calibration shown in Figure 2. In Figure 3 the single-frequency ionospheric results are presented and the difference between the truth calibration (Figure 2) and the smoothed single-frequency calibrations are plotted in Figure 4. For these sample passes, the single-frequency ionospheric calibration captures about 80 to 85 percent of the actual value.

Ground Receivers - For the ground GPS receivers, the ionosphere calibration is obtained with the usual dual-frequency calculations. Full wavelength L_2 is produced using cross-channel correlation in the receiver hardware. During A-S the only difference is that the pseudoranges are CA-code and thus have slightly higher noise characteristics. For the orbit determination processing the effective antenna phase center locations and the observation weights are the only adjustments required.

BASELINE SOLUTION SCENARIO

During normal tracking (no A-S) the L_1 and L_2 carrier signals are modulated with the P-code. In addition, the L_1 carrier is also modulated with the CA-code. For A-S tracking the P-code is replaced by the Y-code (encrypted security code) which makes it impossible for unclassified users to track the L_2 carrier. The L_1 carrier is always available since it is modulated with the CA-code. During A-S, some GPS satellites continue to transmit the normal CA-code and P-code signals. The Block I satellites do not have A-S capabilities and on occasion some of the BLOCK II satellites have not activated A-S.

Carrier phase and P-code pseudorange data are available on the flight receiver at rates of one per second and one per 10 seconds respectively. Pre-processing of the observations consists of detecting and correcting cycle slips, determining and applying TOPEX/Poseidon clock offsets, and decimating to the desired processing rate and calibrating for ionosphere. Since the noise level is different for CA-code and P-code measurements the data weights are chosen to balance this effect in the orbit determination process. Table 1. shows the data rates and weights used for operational orbit determination.

RESULTS

Six 30 hour arcs and one 10 hour arc were processed. Orbit comparisons with solutions from Satellite Laser Ranging (SLR) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) tracking show RMS radial agreement at the sub-decimeter level. Figure 5. shows the GPS carrier phase residual errors between the actual observations and the computed values from the converged solutions. The total and GPSDR only results are provided for day with and without A-S. Orbit comparisons with the official T/P precision orbit ephemeris solutions are provided in Figures 6 and 7. These comparisons show the resulting differences obtained by using the single frequency observations only (i.e., no ionosphere calibration) and the single frequency observation calibrated with the data pre-processing technique described above. Also note that the relative degradation, between the A-S on and off cases, is about two cm radial and 10 to 20 cm in three dimensions.

CONCLUSIONS

Mitigation of the effects of anti-spoofing on the T/P GPS flight receiver observations is achieved by means of a data conditioning technique used prior to orbit adjustment. For the ground receivers a hardware solution exists that effectively eliminates special processing of those data. With these techniques and the initial results of this paper, <u>continuous</u>, subdecimeter RMS radial T/P orbits can be obtained using only GPS observations.

Table 1 - Data Rates and Processing Weights

Data Type	Processing Rate	Weight
T/P P-code Carrier Phase	5 min. (decimated)	2 cm
T/P CA-code Carrier Phase	5 min. (decimated)	15 cm
T/P P-code Pseudo Range	5 min. (decimated)	2 meters
T/P CA-code Pseudo Range	5 min. (decimated)	500 meters
Ground P-code Carrier Phase	5 min. (decimated)	1 cm
Ground CA-code Carrier Phase	5 min. (decimated)	3 cm
Ground P-code Pseudo Range	5 min. (decimated)	1 meters
Ground CA-code Pseudo Range	5 min. (decimated)	50 meters

ACKNOWLEDGEMENTS

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The authors would like to recognize the technical contributions of Peter J. Wolff and Dah-Ning Yuan for their efforts in obtaining the results presented in this paper.

REFERENCES

[1] Bertiger, W., and others, "Early Results from the TOPEX/POSEIDON GPS Precise Orbit Determination Demonstration," AAS-93-154, presented at the Third Annual AAS/AIAA Spaceflight Mechanics Meeting, Pasadena,CA., 22-24 Feb., 1993.

[2] Guinn, J. and P. Wolff, "TOPEX/POSEIDON Operational Orbit Determination Results Using Global Positioning Satellites," AAS-93-573, presented at the AAS/AIAA Astrodynamics Specialist Conference, Victoria,B.C.,Canada, 16-19 Aug., 1993.

[3] Wu, S.C. and others, "Automated Precision Orbit Determination for TOPEX/POSEIDON with GPS," AAS-93-576, presented at the AAS/AIAA Astrodynamics Specialist Conference, Victoria,B.C.,Canada, 16-19 Aug., 1993.

[4] B. Hofmann-Wellenhof and others, *GPS Theory and Practice*, Springer-Verlag, 2nd ed. 1993.

[5] L. Carson and others, "Design and Predicted Performance of the GPS Demonstration Receiver for the NASA TOPEX Satellite," *IEEE Transactions on Communications,* vol. CH-2675, pp.422-454, July 1988.

[6] Srinivasan, J., T. Meehan, and L. Young, "Code and Codeless Ionospheric Measurements with NASA's Rogue GPS Receiver," *Proceedings of Third International Meeting of Navigation Satellite Division,* September, 1989.

[7] Meehan, T. and others, "The TurboRogue GPS Receiver," presented at the Sixth International Geodetic Symposium on Satellite Positioning, Columbus, OH., 18 March 1992.

[8] Wu, S.C., and others, "Minimizing Selective Availability Error on TOPEX GPS Measurements," AIAA-90-2942, AIAA/AAS Astrodynamics Conference, Portland, OR., August, 1990

Figure 1 - Flight Receiver Pseudorange from GPS31 (10 Passes)

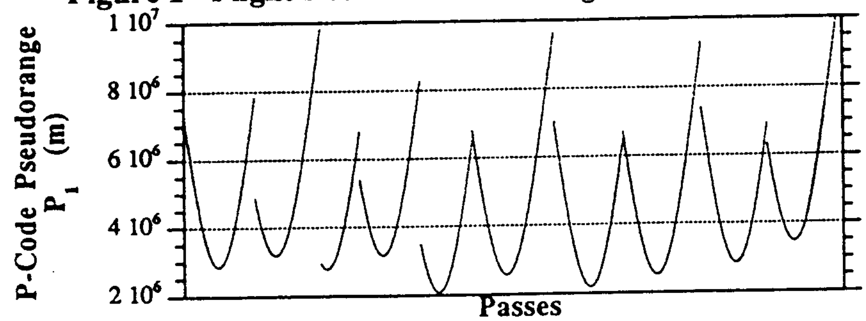

Figure 2 - Dual-Frequency Ionospheric Calibration

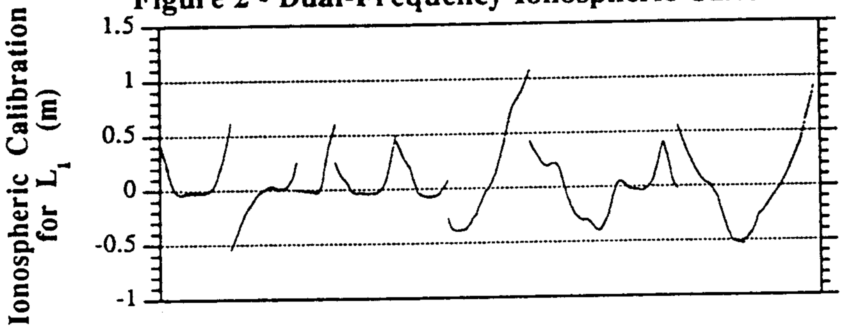

Figure 3 - Single-Frequency Ionospheric Calibration

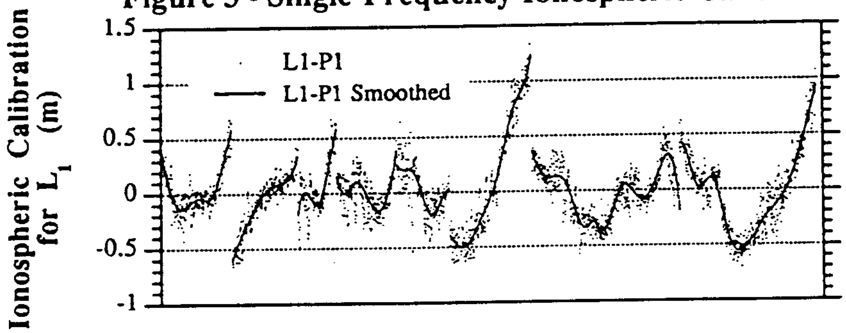

Figure 4 - Dual minus Smoothed Single-Frequency

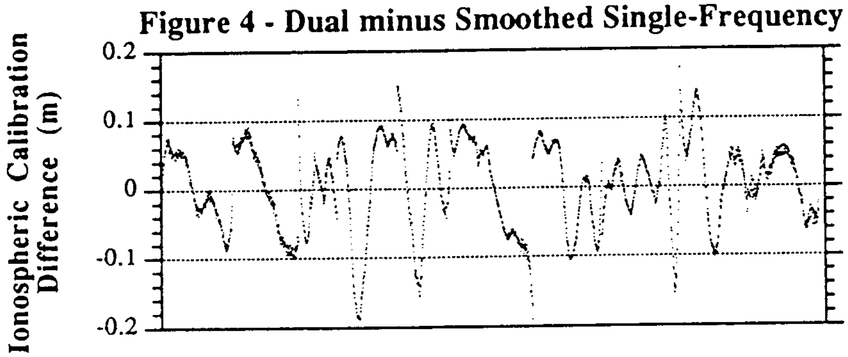

Figure 5 - GPS Observation Residuals
(TOPEX and 6 Ground Stations)

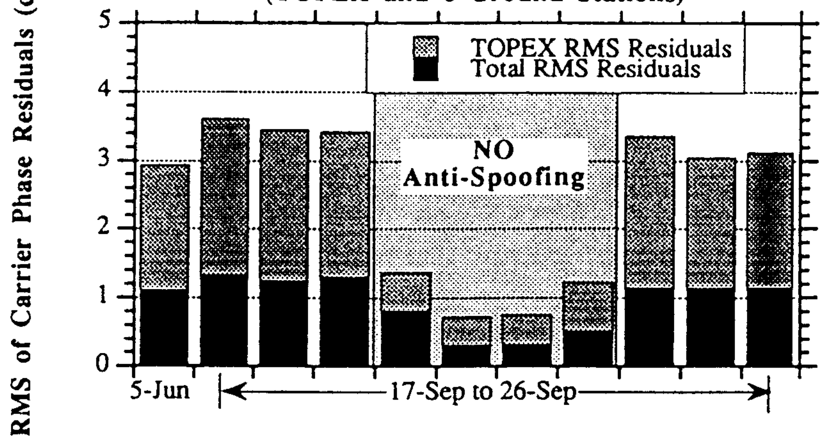

Figure 6 - Radial Orbit Comparisons with NASA POE

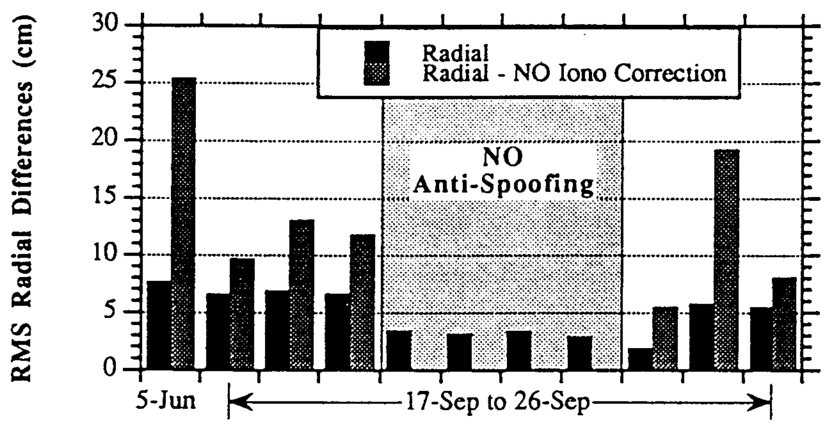

Figure 7 - 3D Orbit Differences with NASA POE